THE MILKY WAY AND THE TULLY–FISHER RELATION

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Abstract We present an updated estimate of the surface density and surface brightness in B, V, I of the local Galactic disc, based on a model for the "Solar cylinder" calibrated to reproduce Hipparcos and Tycho star counts. We discuss the mass–to–light ratio of the local stellar disc and infer the global luminosity of the Milky Way, which results underluminous with respect to the Tully–Fisher relation.

1. Introduction

In the past two decades there has been a steady effort to determine the surface mass density of the local Galactic disc, eventually excluding any significant evidence for disc dark matter (e.g. Holmberg & Flynn 2000, 2004). As to the local luminosity surface density, the infra-red structure of the Milky Way seems well understood (Gerhard 2002), but studies in the optical typically date back to the '80s (de Vaucouleurs & Pence 1978; Ishida & Mikami 1982; Bahcall & Soneira 1980; van der Kruit 1986). The surface luminosity and colours of the "Solar cylinder" are useful comparison points in extragalactic studies, and to constrain chemo–photometric models of the Milky Way, which often serve as a calibration point for the modelling of disc galaxies (Boisser & Prantzos 1999). Estimating the local surface brightness across many bands requires accurate knowledge of the vertical structure of the disc; in this respect, Galactic models have much improved after Hipparcos. The time is ripe for an update.

2. The Galactic model and the Solar cylinder

We derive the surface brightness of the local Galactic disc from the stellar census of the Hipparcos and Tycho catalogues, combined with a model for the vertical structure of the disc. The model consists of a thin disc, a thick disc and a stellar halo (irrelevant in this study). The vertical structure is modelled as a series of components (e.g. Bahcall & Soneira 1980; van der Kruit 1988) with a different scaleheight for each component: main sequence stars of different M_V, red giants and supergiants. The V band luminosity function and the colour distributions ($B-V$, $V-I$) vs. M_V are calibrated to reproduce the

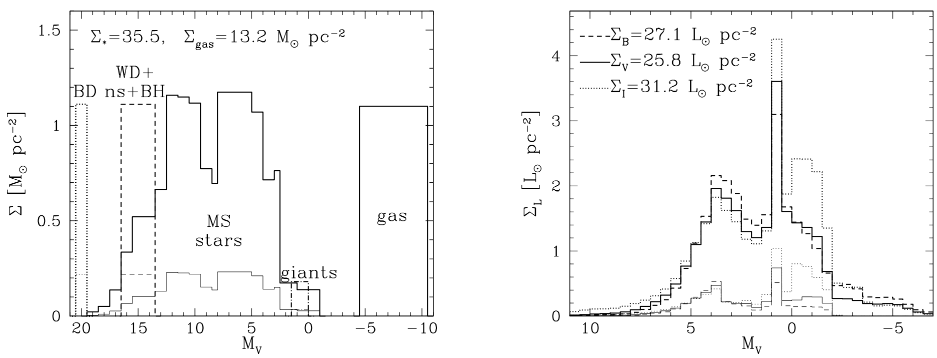


Figure 1. Mass model by Holmberg & Flynn (2004) and corresponding surface luminosity histograms in B, V, I. *Thick lines*: total mass/luminosity; *thin lines*: thick disc contribution.

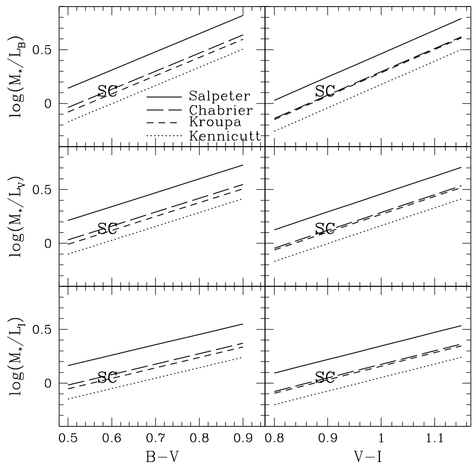
Hipparcos/Tycho star counts. The mass model is constrained from the kinematics and the vertical distribution of AF stars (within 200 pc) and of K giants (both local and out to $\sim$1 kpc toward the South Galactic Pole); for details see Holmberg et al. (1997); Holmberg & Flynn (2000, 2004).

Fig. 1 shows (a slightly updated version of) the mass model of Holmberg & Flynn (2004), and the corresponding B, V, I band luminosity contributions of stars by absolute M_V; the resulting global surface mass/luminosity densities are also indicated. The luminosity peak around $M_V \sim 0.5$ is due to clump giants; giant stars contribute 26 (40, 56) % of the B (V, I) surface luminosity.

Fig. 2 lists the surface brightness and colours we derive for the local thin, thick and total disc; and the stellar mass–to–light ratio (M_*/L) of the Solar cylinder. We also compare our results to the theoretical colour–M_*/L relations predicted by the population synthesis models of Portinari et al. (2004) for different Initial Mass Functions (IMFs). Our SC values are in excellent agreement with the predictions for the Kroupa and Chabrier IMFs, which have been derived for the Solar Neighbourhood — a successful consistency check.

3. From the Solar cylinder to the Milky Way

From the surface luminosity (or density) at the Solar radius one can infer the total luminosity (or mass) of the Galactic disc by assuming an exponential radial profile, and the result is quite robust to the assumed scalelength R_d (e.g. Sommer–Larsen & Dolgov 2001). The Solar cylinder probes an inter-arm region so we must allow for the spiral arm contrast to derive the actual azimuthally averaged surface brightness at the Solar radius. We will henceforth focus on the I band as this is most typical for Tully–Fisher (TF) studies and spiral arms are not expected to induce major effects. In K band the spiral arm enhancement is only about 10% (Drimmel & Spergel 2001; Gerhard 2002) and



	thin disc	*thick disc*	*total*
μ_B	23.7	25.7	23.5
μ_V	23.1	24.8	22.9
μ_I	22.3	23.7	22.0
$(B-V)$	0.53	0.90	0.59
$(V-I)$	0.84	1.13	0.89

$\frac{M_*}{L_B}$	$\frac{M_*}{L_V}$	$\frac{M_*}{L_I}$
1.3	1.4	1.1

Figure 2. Model results for the surface brightness and colours of the Solar cylinder, and corresponding location with respect to the colour–M$_*$/L relations predicted for different IMFs.

in the I band the effect should be comparable (Rix & Zaritsky 1995). Fig. 3a shows the total I band luminosity and stellar mass of the Galactic disc inferred from the local surface brightness and density, including a 10% correction for spiral arms. We must further add the bulge contribution to get the total luminosity; the bulge K band luminosity is $\sim 10^{10}$ L$_\odot$ (Kent et al. 1991; Gerhard 2002); we assume the same value in I band, which is probably an overestimate as the bulge is mostly composed of older, redder populations. The total I band luminosity of the Milky Way is thus $\sim 4 \times 10^{10}$ L$_\odot$, or $M_I \sim -22.4$. With a circular speed of $\sim 220\pm20$ km/sec, the Milky Way turns out to be underluminous with respect to the TF relation defined by external spirals (Fig. 3b).

4. Conclusions

We have presented an updated estimate of the B, V, I surface brightness and colours of the "Solar cylinder" and reconstructed from the local disc brightness the total luminosity of the Milky Way, which appears to be underluminous with respect to the TF relation; although the discrepancy is not dramatic when considering the scatter in the TF relation and the uncertainty in the Milky Way values (20% assumed for the luminosity in Fig. 3). The offset might be partly due to a colour effect, if the Milky Way is a redder and earlier type spiral than the Sbc-Sc galaxies defining the TF relation (Portinari et al. 2004); however, the disc locally is quite blue ($B-V \sim 0.6$) which does not argue for significant colour and M$_*$/L offsets between the Milky Way and Sbc–Sc spirals. All in all, the offset might indicate a problem with the luminosity zero–point of the

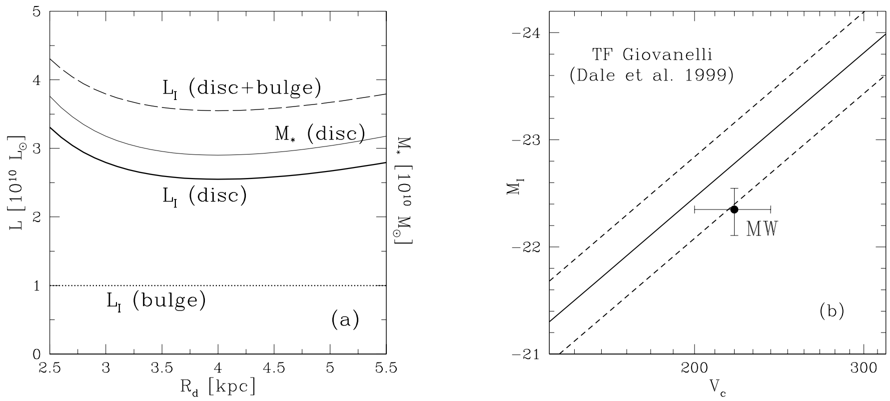


Figure 3. *(a)* Total I band luminosity of the Mily Way inferred as a function of the assumed disc scalelength R_d. *(b)* Location of the Milky Way with respect to the I band TF relation.

TF relation, and/or with the M$_*$/L of disc galaxies. A similar conclusion is suggested also by semi–analytic models of galaxy formation (Dutton et al. 2004). The issue certainly deserves further investigation.

We are presently refining our I band luminosity estimate with the aid of DENIS and other star counts, and defining better our errorbars; we are also extending our surface brightness determination to other photometric bands, especially in the infrared utilizing DENIS and 2MASS.

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